

Probing sub-GeV dark matter with SPICE

Vetri Velan | TESSERACT Collaboration
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The Duality of Particle Detection

Targets

Noble liquids

Crystals

Liquid
scintillators

Gaseous
detectors

Etc.

Sensors

Photomultiplier
tubes

Transition-edge
sensors

Silicon
Photomultipliers

SNSPDs

Etc.

Need complementarity between the target and the sensor

TESSERACT

- TESSERACT project: Transition-Edge Sensors with Sub-eV Resolution and Cryogenic Targets
- Collaboration includes ~40 scientists, advancing the use of TESs and cryogenic targets for DM searches
- Three target materials: superfluid helium-4 (called HeRALD), sapphire and GaAs (collectively called SPICE)
- World-leading projected sensitivity to DM-nucleon and DM-electron interactions via new mediators, and absorption of bosonic DM



UC Berkeley



Caltech



FLORIDA STATE

M UNIVERSITY OF MICHIGAN



TEXAS A&M UNIVERSITY

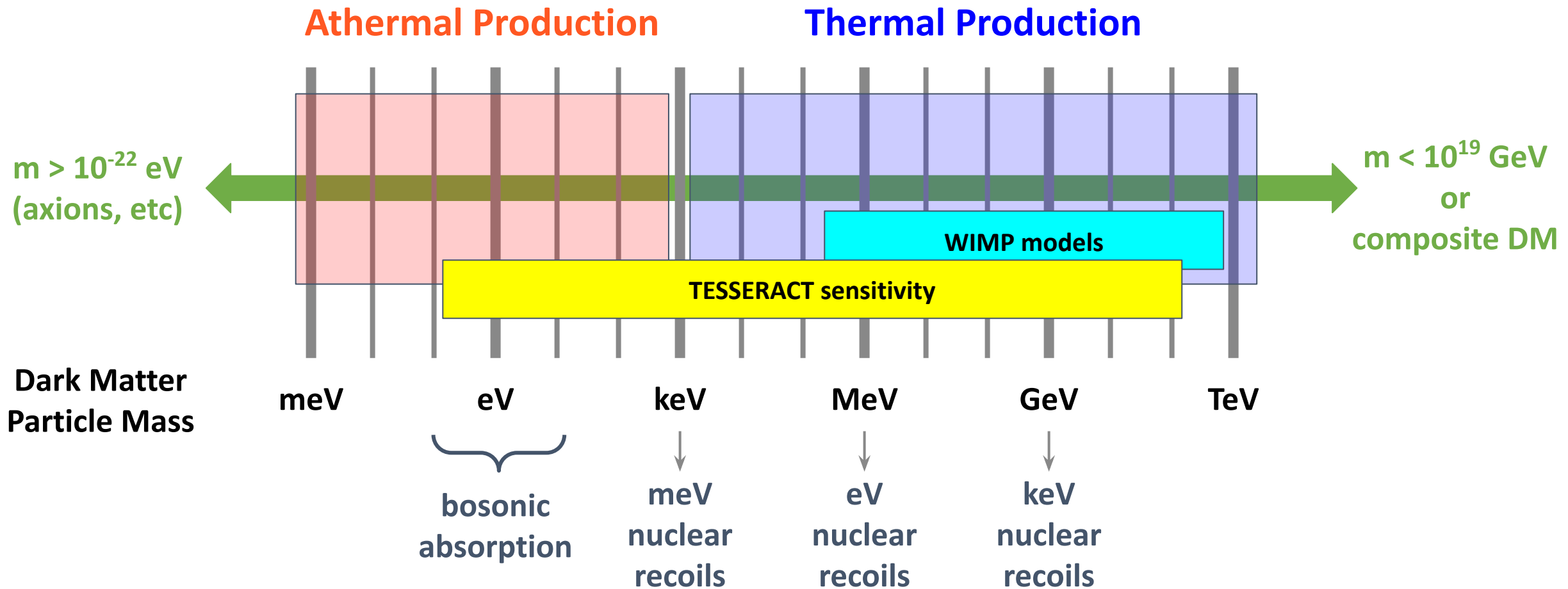
Argonne NATIONAL LABORATORY

UMass Amherst



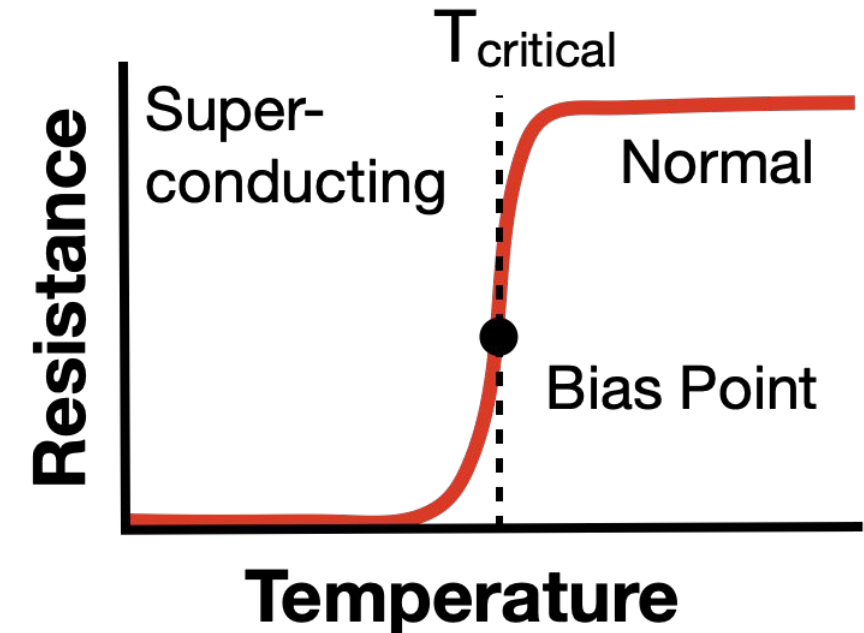
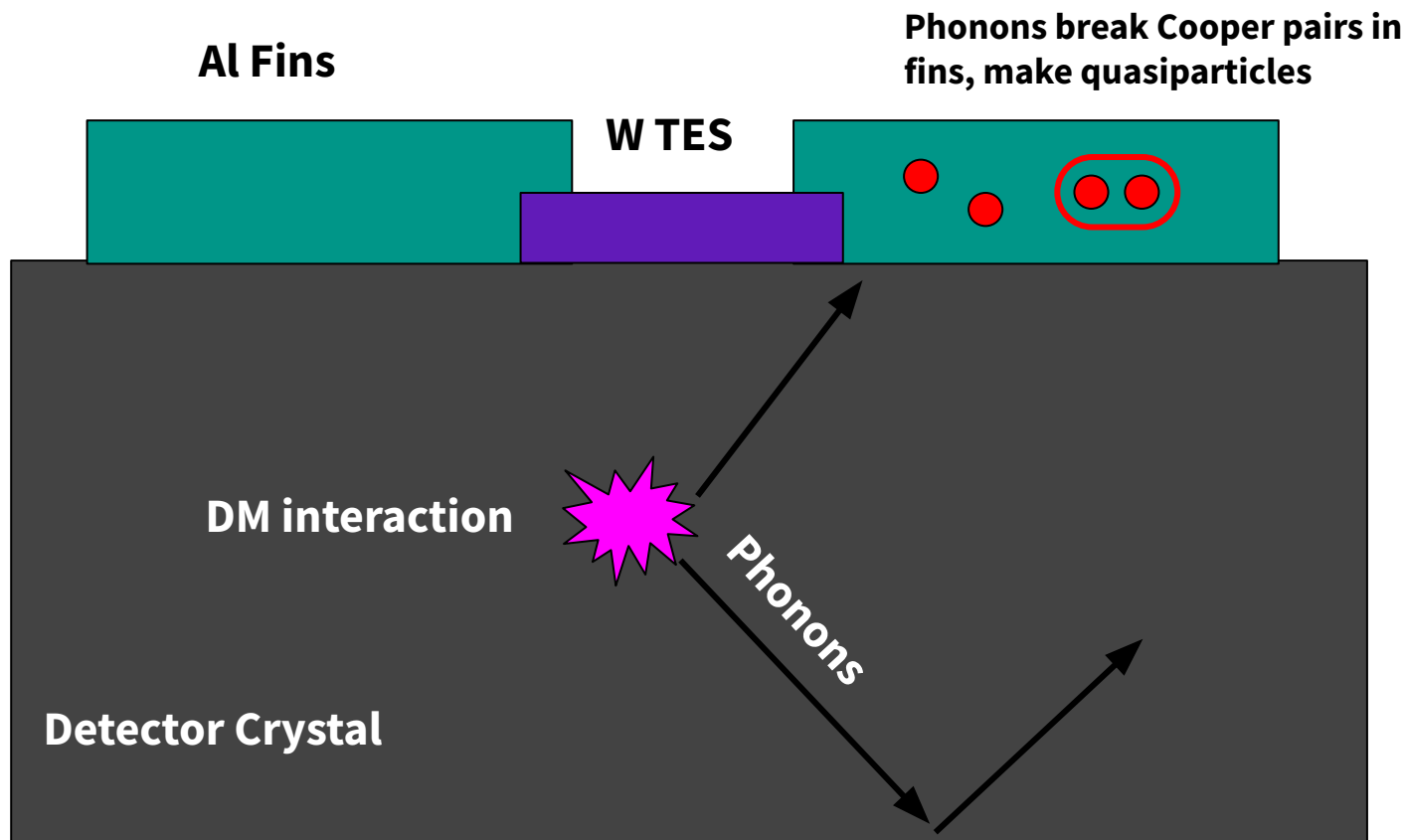
Universität Zürich^{UZH}

Projected Sensitivity to Dark Matter



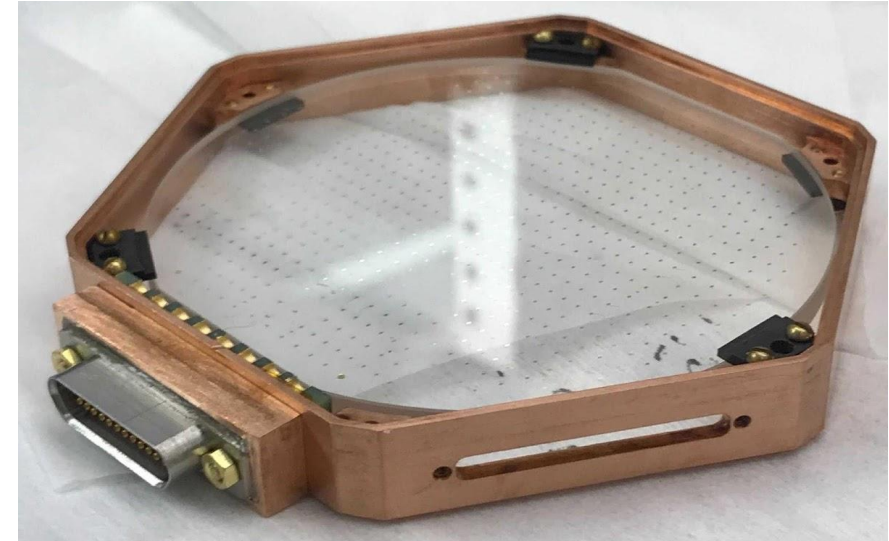
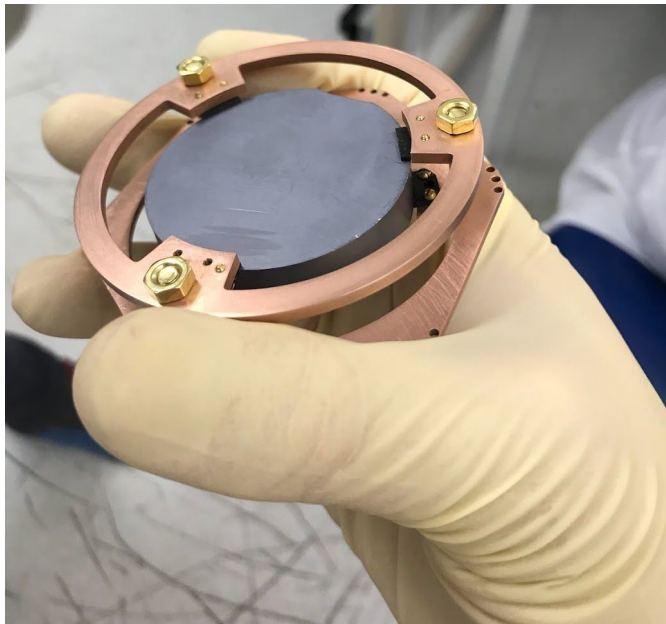
Transition-Edge Sensors (TES)

Low-temperature, small-volume sensors →
better energy resolution and lower threshold



SPICE - Polar Crystals

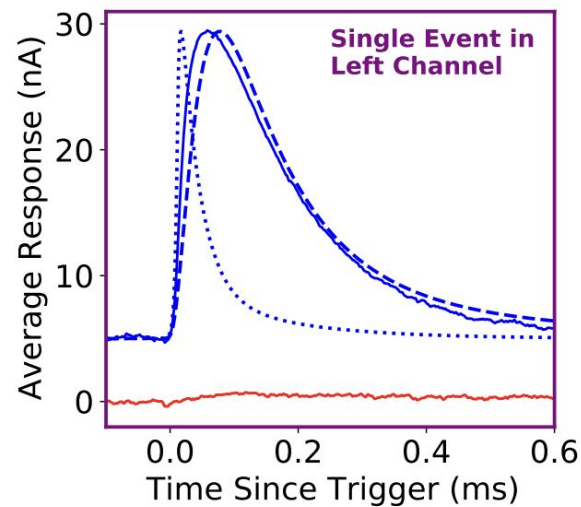
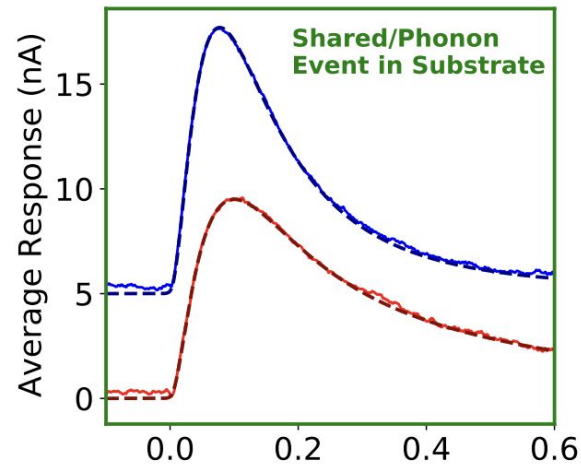
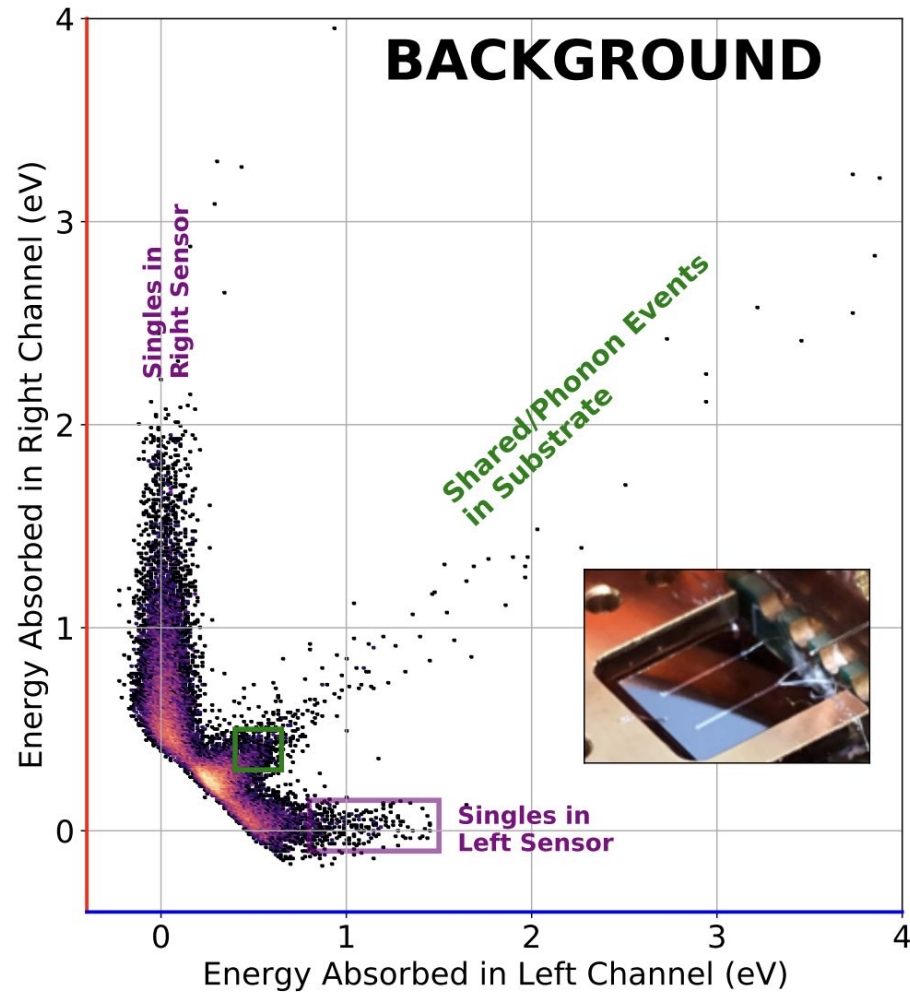
- **Sapphire** (Al_2O_3):
 - **Sapphire** supports optical phonon modes.
 - DM recoiling off the lattice, 'exciting a **phonon**'
 - Coupling to E&M-like inputs due to electric dipole → **dark photon sensitivity**



- **GaAs:**
 - **Polar crystal & bandgap** well matched to kinematic region of low mass DM
 - **Background discrimination** using phonon/photon ratio
 - Photon-photon and phonon-phonon coincidence can reduce instrumental bkgds
 - High light yield (125 ph/keV, 1904.09362)

Tackling the Low Energy Excess

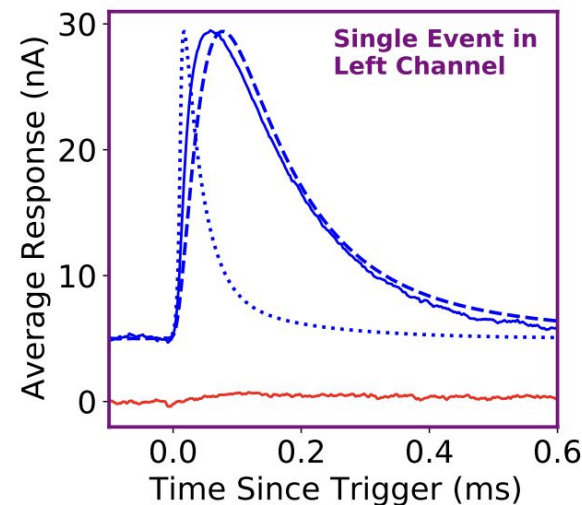
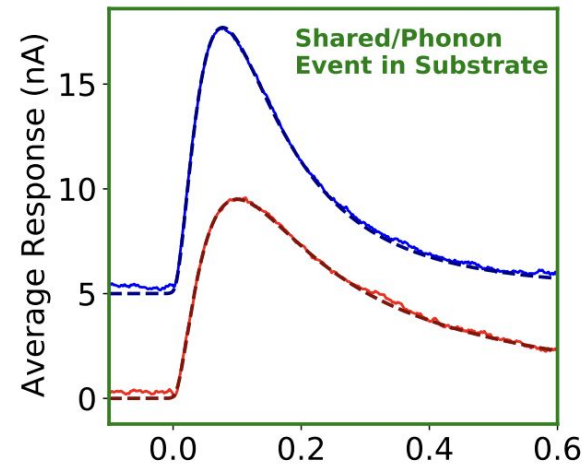
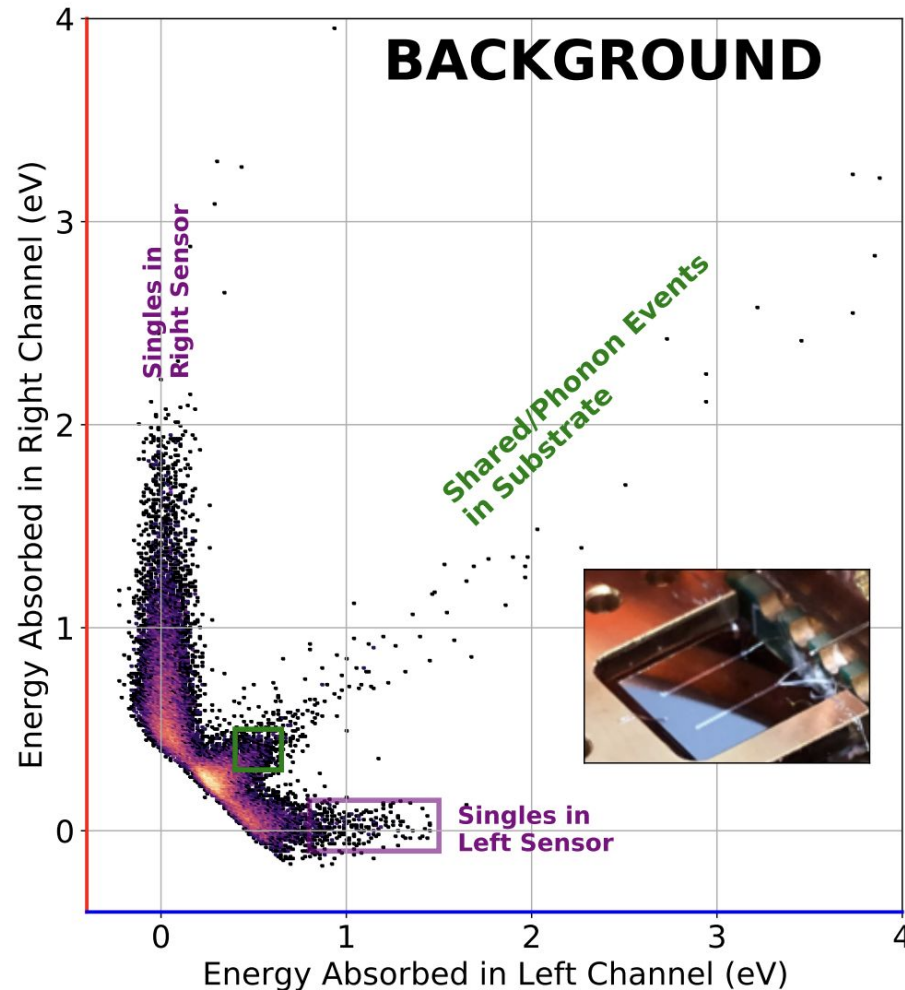
arXiv:2410.16510



- Low-energy excess (“LEE”) is a known problem in our field
- Use two channels on one substrate to understand the source
 - Film stress? Photons?
- 0.1 cm³ volume Si crystal with two channels of 25 tungsten TESs (~ 48 mK T_c). Aluminum phonon collection fins cover 1.38% of the device’s surface.
- Recent progress at arXiv:2410.16510

Tackling the Low Energy Excess

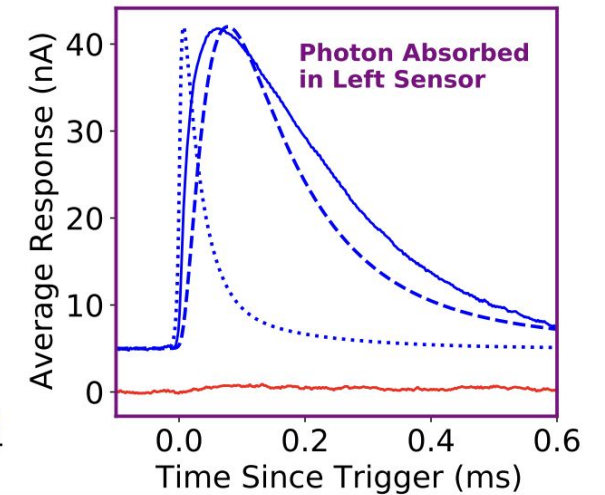
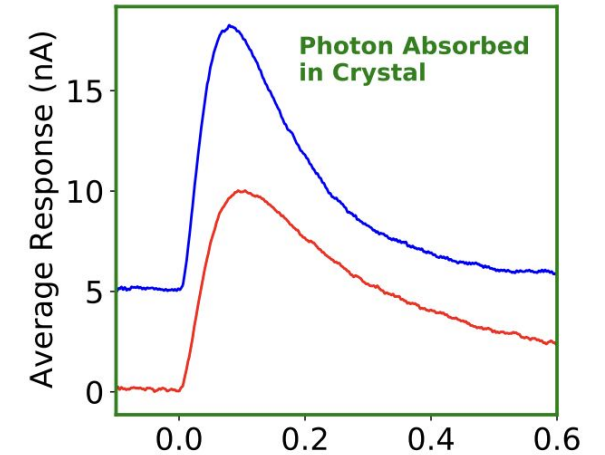
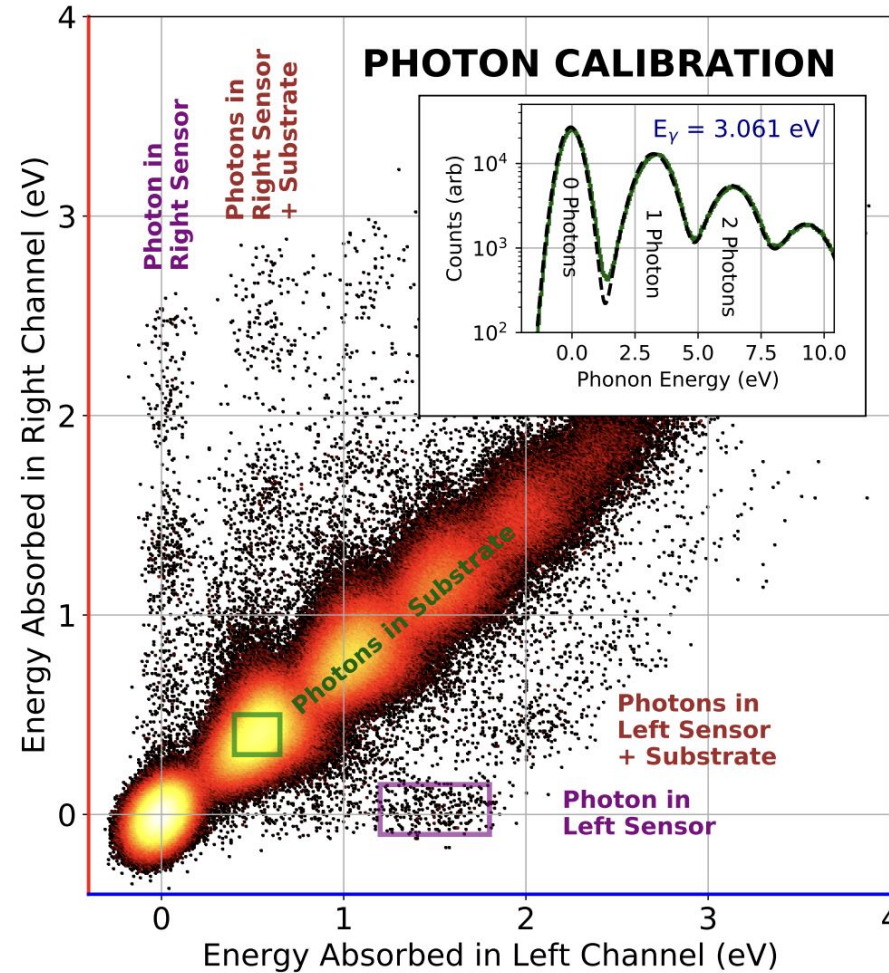
arXiv:2410.16510



- Two classes of events: “shared” and “singles”
- Shared events are associated with athermal phonon bursts in the Si substrate
 - DM background!
- Single events are associated with phonon bursts in the aluminum fins, which are mostly absorbed locally in a given channel
 - Some phonons leak out into the phonon system and are seen by the other channel

Fiber Optic Photon Calibration System

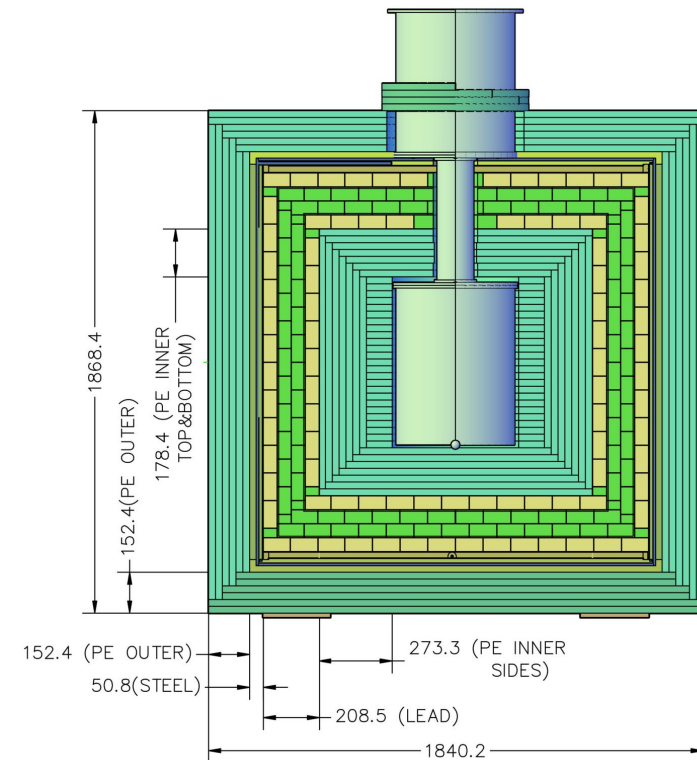
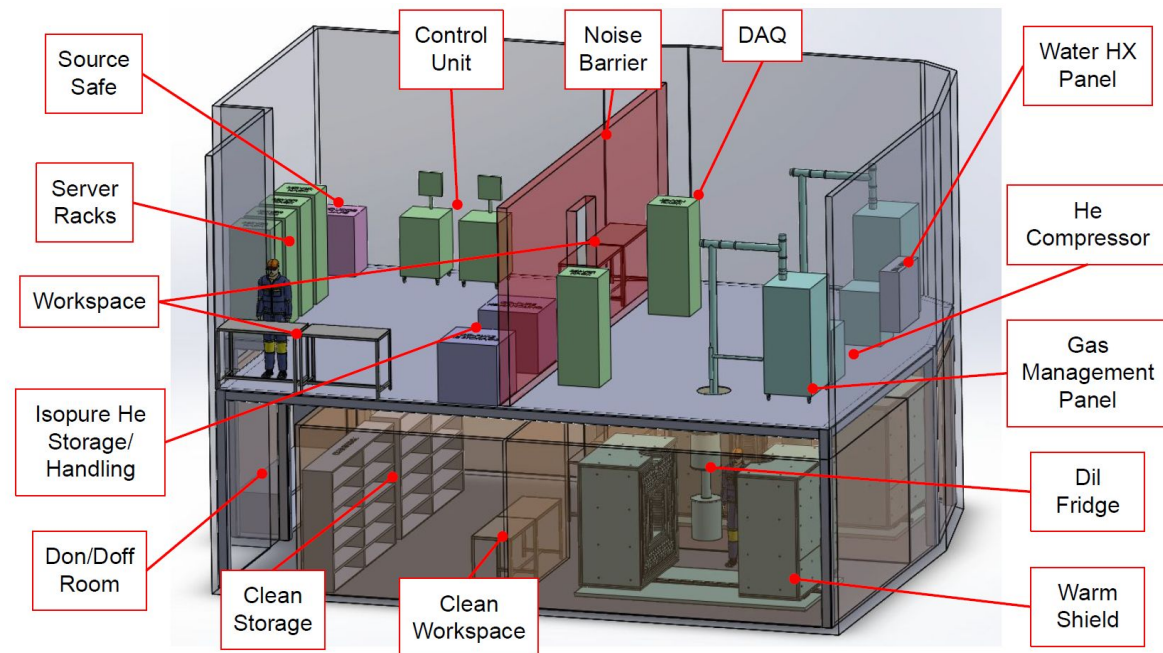
- Short bursts of 3 eV photons directly onto the sensors
- Photons observed, mediated through phonons
- **World-leading baseline phonon energy resolution of $\sigma = 375.5 \pm 0.4$ meV**



arXiv:2410.16510

TESSERACT at Modane (LSM)

- Selected for DOE funding starting FY25
- Plan for two identical setups - each able to house a target
- Installation begins 2025!



What to remember

- The SPICE experiments and the TESSERACT collaboration are making rapid progress towards a world-leading dark matter search
- Informed by recent advancements in sensor technologies, target dynamics, and understanding of LEE backgrounds